§11. Turbulence Diagnostic Simulator for Analyzing Structural Formation in Magnetically Confined Plasmas

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Turbulent structures affect the level of anomalous transport, and their formation mechanism is one of the crucial issues in the fusion plasmas [1]. Therefore, quantitative analyses of their formation and self-regulated mechanism must be carried out. We have been developing a turbulence diagnostic simulator, which numerically simulates plasma turbulence and data analyses on the simulation data, as same in the experiments [2,3]. The simulator studies the fundamental mechanisms of turbulent structural formation, and aids the development of the data analysis technique to deepen our physical understandings. For the first step to study fusion plasmas, we have carried out numerical simulations in cylindrical plasmas to identify the bifurcation phenomena of the turbulent structure.

A three-field (density, potential and parallel velocity of electrons) reduced fluid model was extended to describe the resistive drift wave turbulence in a linear device [4]. The plasma has a simple cylindrical shape, and the magnetic field has only the component in the axial direction with the uniform intensity. Plasma experiments in the simple linear configuration have been carried out recently for quantitative understandings of the structural formation. According to experiments, high density (n_e > 1×10^{19}[m^{-3}]) and low temperature (T_e < 5 [eV]) plasmas in an argon discharge are analyzed. The density of neutral particles is high even in the plasma core region, so the effect of neutral particles is taken into consideration.

A nonlinear simulation has been performed to examine the saturation mechanism of the resistive drift wave turbulence. The electron collisions destabilize and the ion-neutral collisions stabilize the resistive drift wave. The calculation with a fixed particle source has been carried out. A zonal flow and a poloidally localized turbulent structure, which has the typical temporal scale of the streamer, are formed selectively by nonlinear couplings of unstable modes by changing ion-neutral collision frequency ν_{in}, which represents the strength of the damping force of the zonal flow and the driving force of the drift wave instability.

Analyses simulating the single and multi probe measurements have been carried out to clarify the difference of the spatio-temporal structures in the bifurcation [2]. Intermittent behavior appears in the zonal flow case. On the other hand, there is long sustainment of the bunched structure with a strong radial correlation in the streamer case. Here, we show the spatio-temporal structures from the poloidal profile. The poloidal probe array is installed to show the poloidal profile in the laboratory plasmas [5]. A time evolution of the poloidal profile of the electrostatic potential is calculated simulating the measurement. Two-dimensional Fourier decomposition gives the spatio-temporal spectrum of the potential as in Figs. 1. In the zonal flow case, low m modes with weak dispersion, which are linearly unstable, are excited and show the broad band spectrum. On the other hand, frequencies of the dominant modes are close to each other, and their harmonics are excited in the streamer case. The rather coherent spectrum appears in this case. The spatio-temporal spectra show clear difference between the zonal flow and streamer case.

The spatio-temporal spectrum shows the dispersion relation of the excited modes. The instantaneous linear dispersion relation is calculated with the density and potential profile in the nonlinear saturated state, and is compared with that of the excited modes in the streamer case (Fig. 1 (b)). The modes with m = 3 - 5, which have the largest amplitudes, are linearly unstable. A theoretical study showed that unstable modes with dispersion relation ω' (k) strongly induce modes with relation $\omega(k) = N\omega'(k/N)$ (N=2,3,4…) by nonlinear coupling [6]. The sharp peaks satisfy those relations, which are plotted by dashed curves in Fig. 1 (b).

In this way, diagnostics on numerical data is useful to capture the fundamental characteristics of turbulence. This is the first step for integrated comparison between experiments and numerical simulations by using a long series of three-dimensional turbulence data to understand the global transport phenomena. Applying the results obtained in the simulations in cylindrical plasmas, we are developing the turbulence diagnostic simulator in toroidal plasmas. The spatio-temporal data of turbulent fields are generated by global simulation, using a fluid model describing drift-interchange instability. The analyses as same in the experiments are made on the simulation data, and comparison with experiments will be carried out.

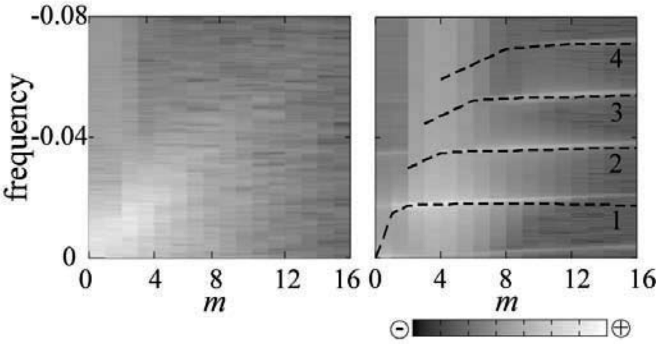

Fig.1: Spatio-temporal spectra at r/a = 0.5 and z/λ = 0.375, in the case with (a) a zonal flow and (b) a streamer, where a is the minor radius and λ is the axial length of the cylindrical plasma. In the streamer case (b), the dispersion relations of linear eigenmodes and quasi-modes induced by eigenmodes are indicated by dashed lines 1 and 2-4, respectively.

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